Simulation of Tropical Storms with High-Resolution Versions of the GEOS-5 Model

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Outline

1. Impacts of cumulus parameterization for high-resolution runs of 25-50 km

   - Gradually turning off cumulus parameterization

2. Modification to the cumulus scheme

   - Stochastic determination of cumulus entrainment

   - Mean/Variance/MJO

3. Tropical Storm Simulations

   - Structure/Intensity

   - Ensemble experiments and interannual variability

4. Summary

Goddard Earth Observing System version 5 (GEOS-5)

- Finite Volume (FV) dynamical core (Lin and Rood, 1996; Lin 2004) with 72 vertical levels (top: 0.01 hPa)
- RAS convection (Moorthi and Suarez, 1992)
- Chou –Suarez Radiation (1994;1999)
- Prognostic Clouds (Bacmeister et al., 2000, 2006)
- Modified Lock Turbulence (Lock et al., 2000)
- Catchment LSM (Koster et al., 2000)
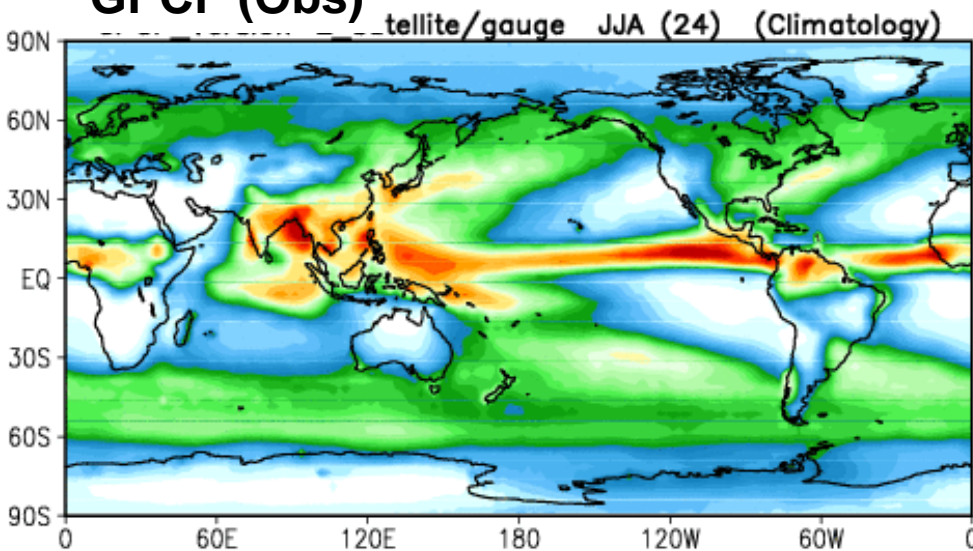- Gravity Wave Drag (NCAR)

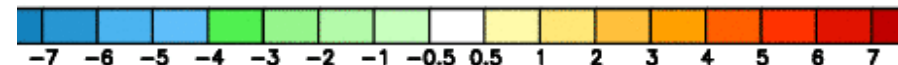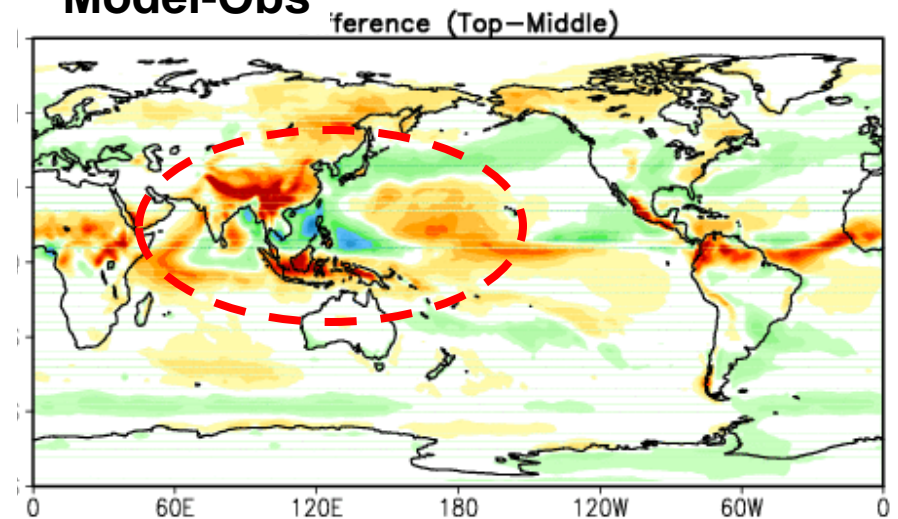# Climate Simulation of GEOS-5
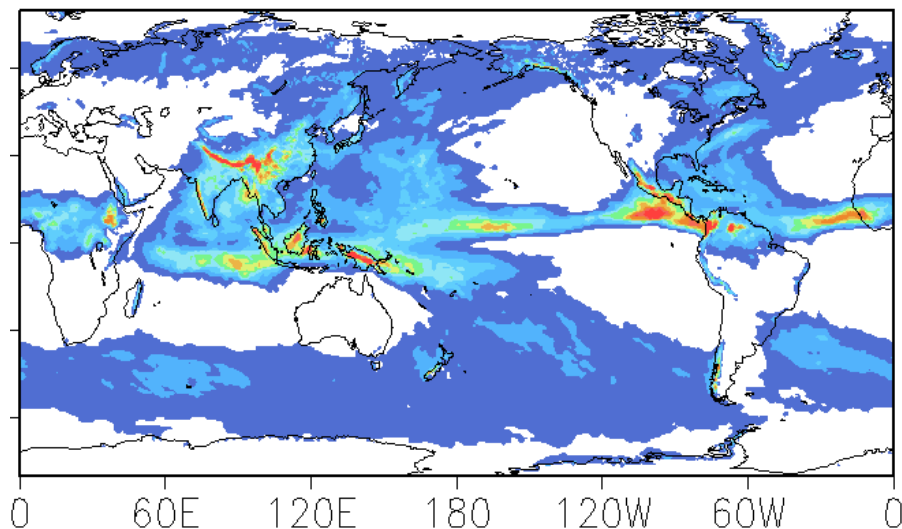## AMIP with 100 km Resolution

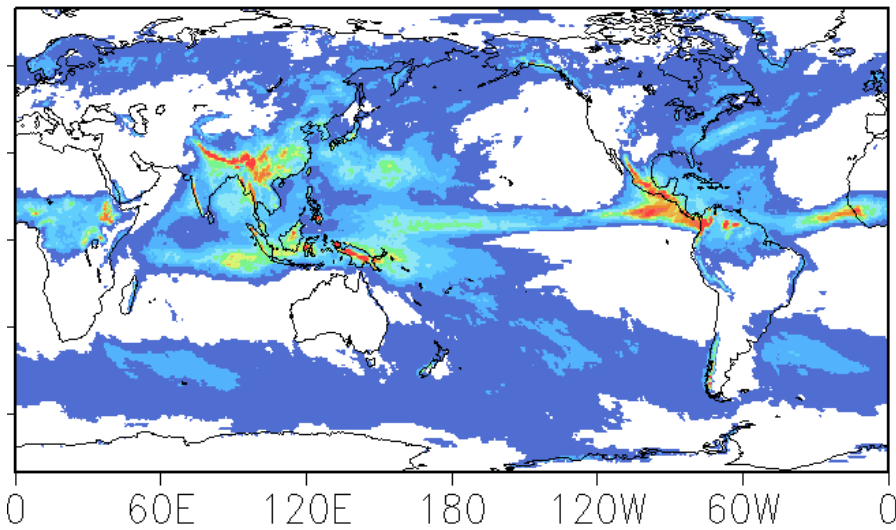**GEOS-5 (Model)**
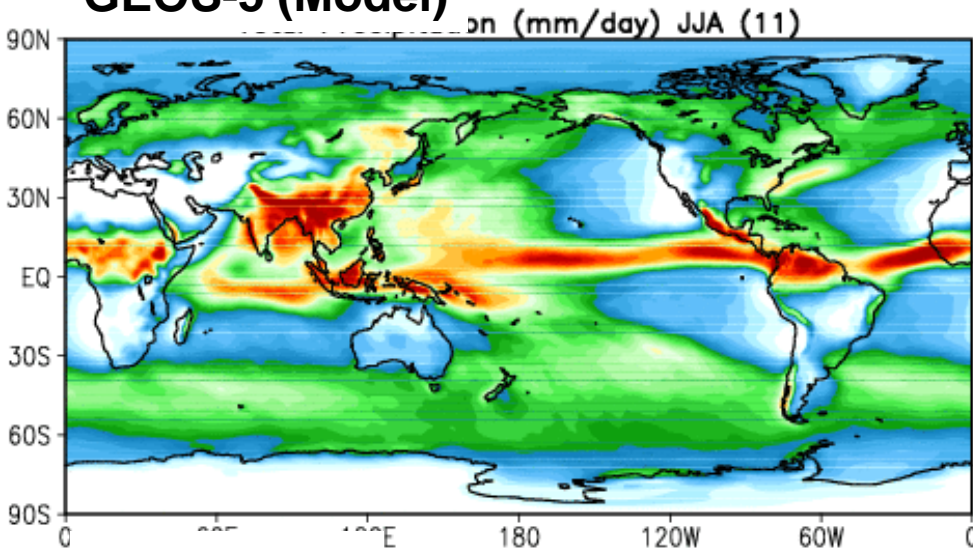
GPCP (Obs)

Model-Obs

Significant biases in monsoon/tropical diabatic heating
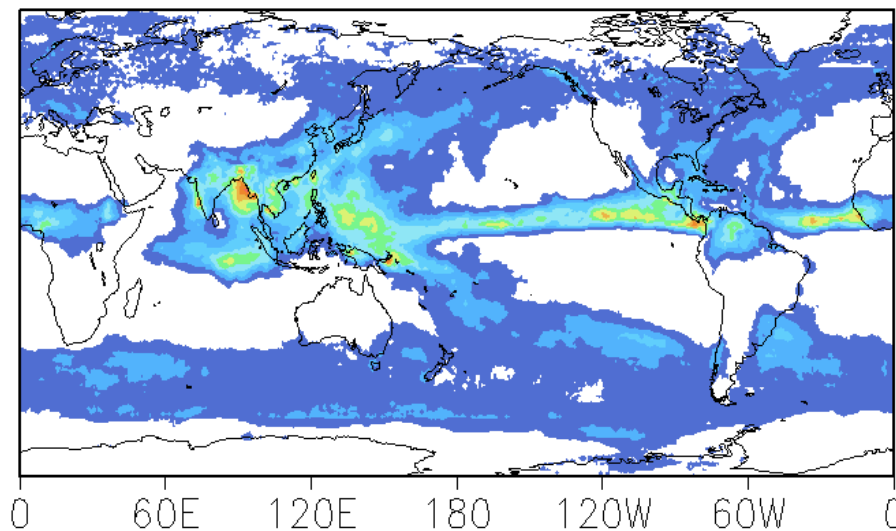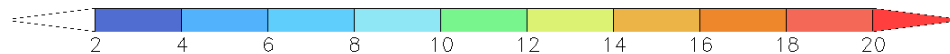
GEOS-5 50-km Simulations

GEOS-5 25-km Simulations

GPCP Observation

High-Resolution
Simulations by
GEOS-5
(JJA 2005-2006)

mm/day

Impacts of Cumulus Parameterization in 25-50km resolutions

- **Dim out convection scheme**

   Successively decrease the level of convective adjustment in the model (*increase the relaxation time scale*, τ in the Relaxed Arakawa-Schubert
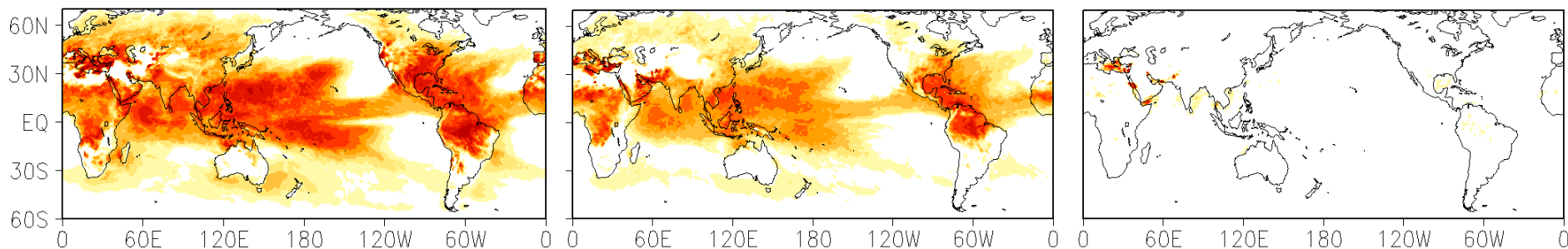
$$M_B \sim -\frac{dA}{dt} = \frac{(A - A_c)}{\tau}$$

M_B: mass flux at cloud base
A : cloud work function (~ CAPE)
A_c: critical cloud work function
τ : relaxation time scale

Ratio of Convective Rainfall to the Total Precipitation
(JJAS)

50-km Resolutions

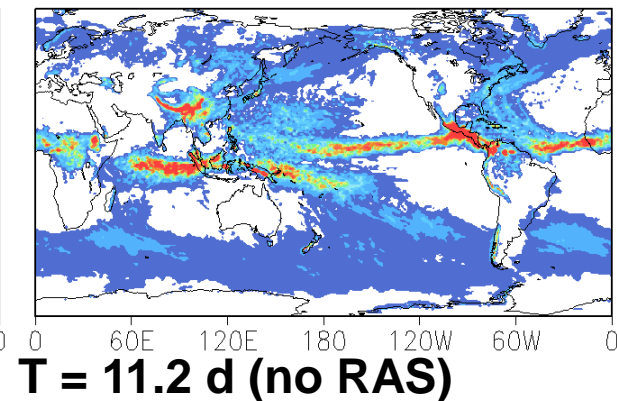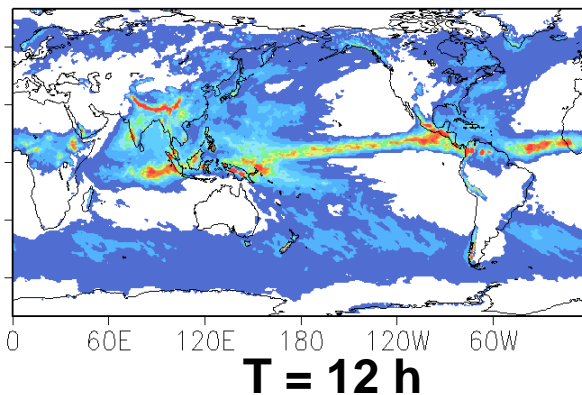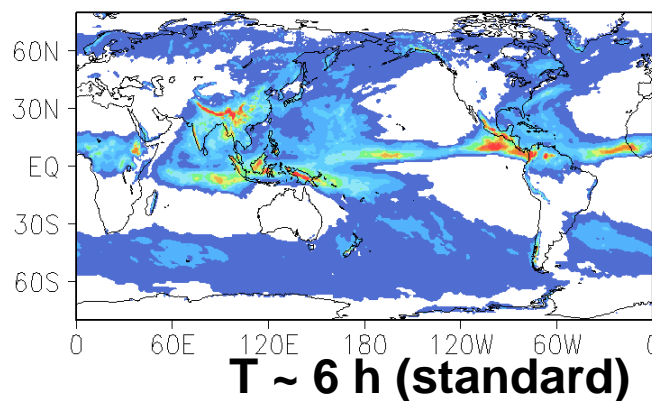T ~ 6 h (standard)   T = 12 h   T = 11.2 d

[%]
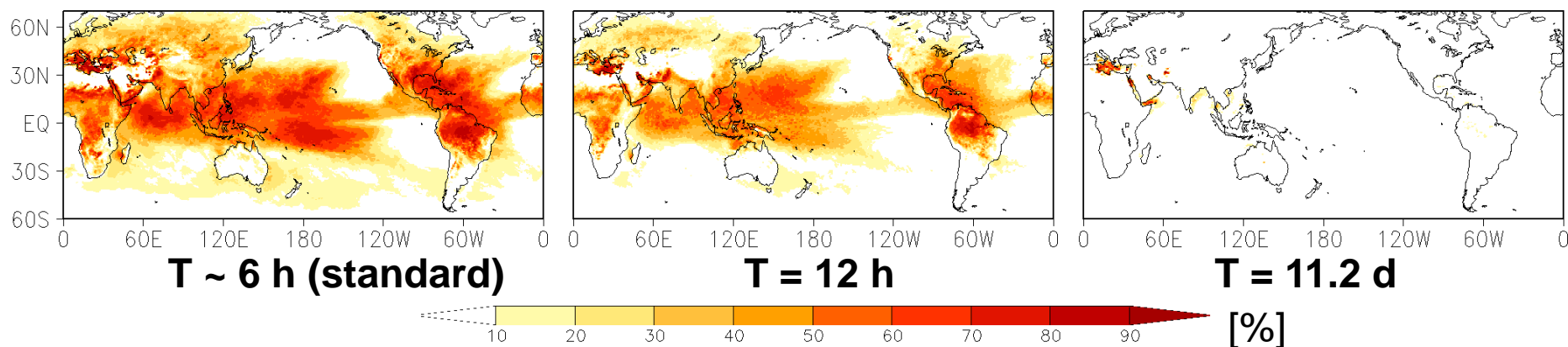
25-km Resolutions

Seasonal-mean precipitation (JJAS, 2005-06)

GPCP

50-km Resolutions
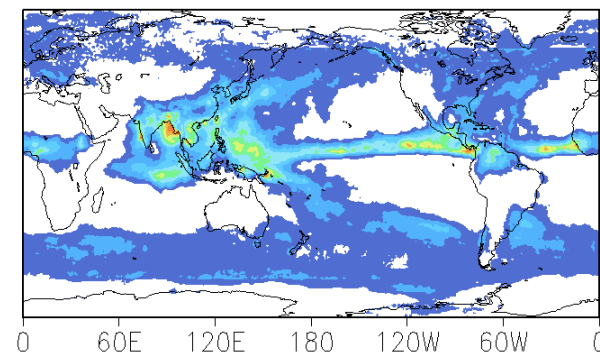
T ~ 6 h (standard) **T = 12 h** **T = 11.2 d (no RAS)**
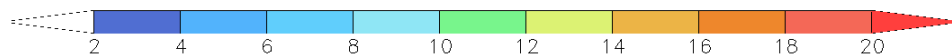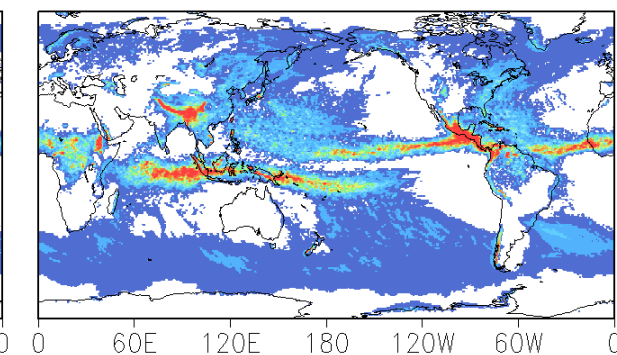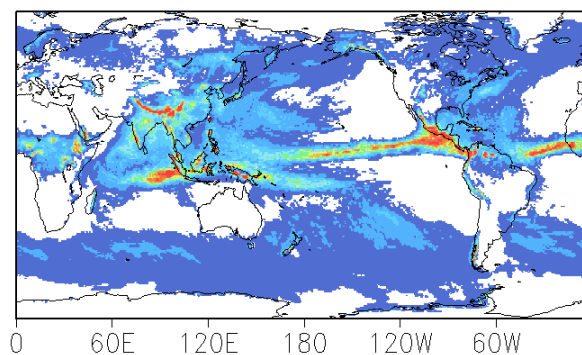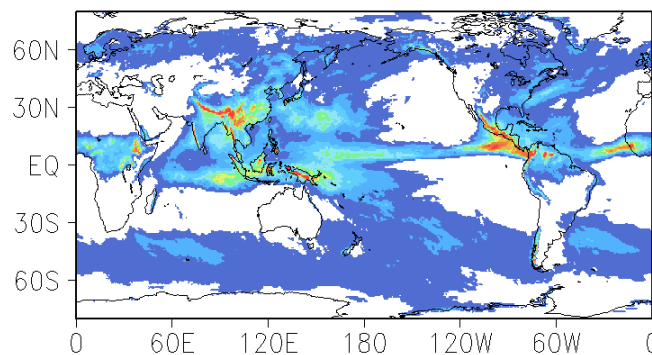
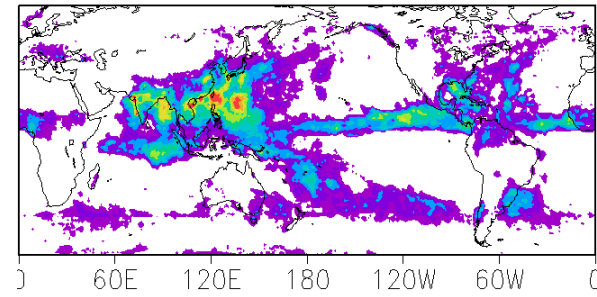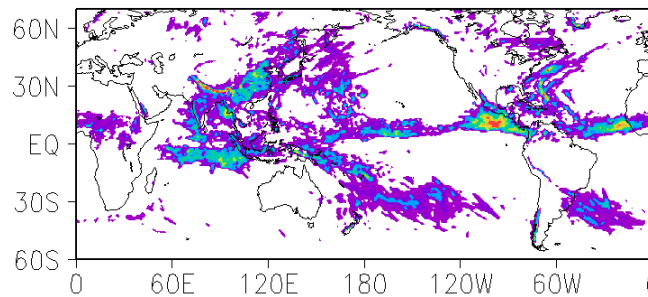**25-km Resolutions**

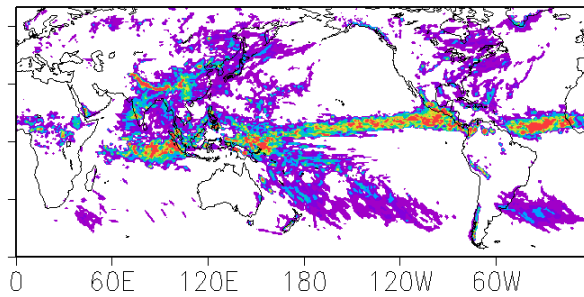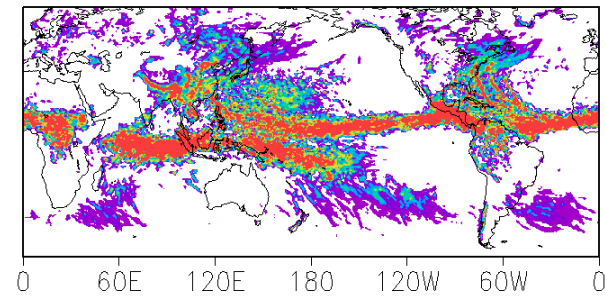# Variance of Daily Precipitation (JJAS)
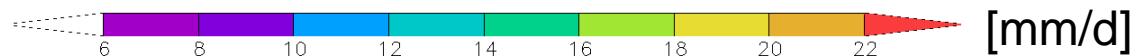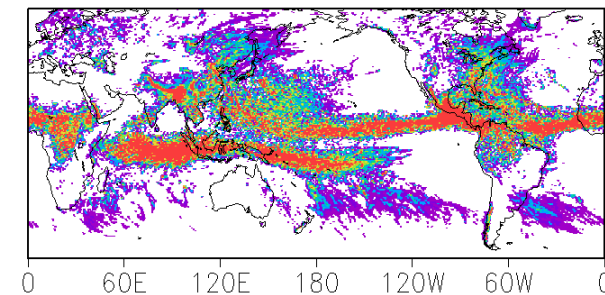

(e) GPCP

50-km Resolutions

T ~ 6 h (standard)   **T = 12 h**   **T = 11.2 d**

25-km Resolutions

[mm/d]

6   8   10   12   14   16   18   20   22
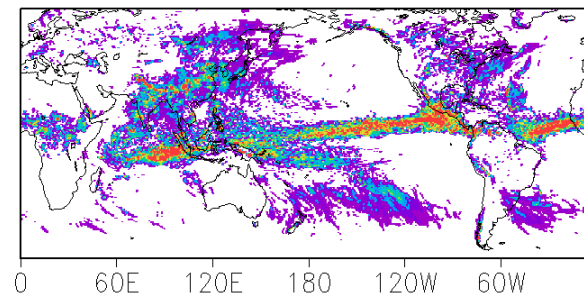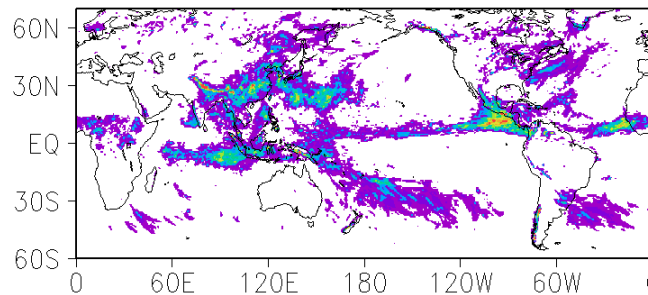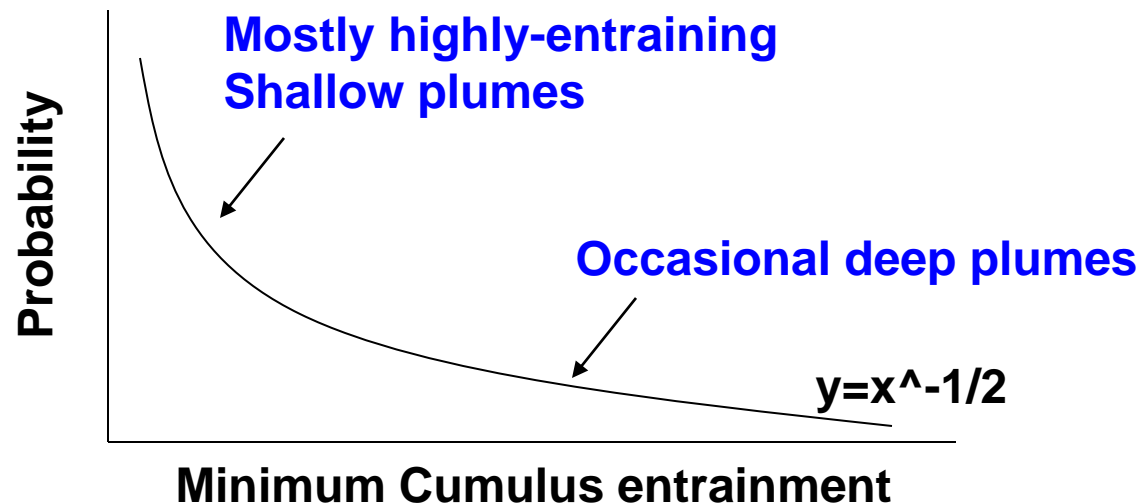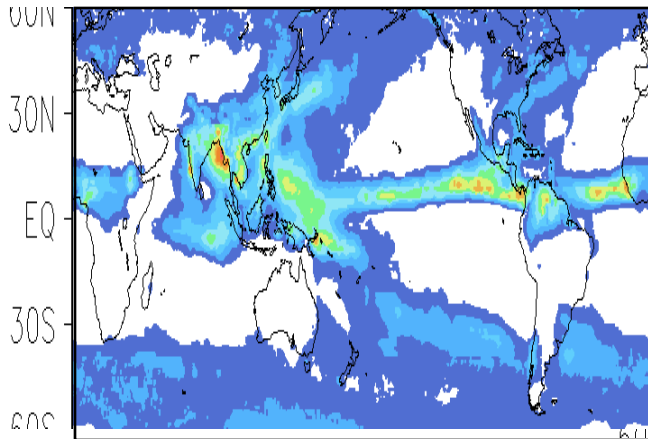
Stochastic Determination of Cumulus Entrainment in RAS

- Based on Tokioka et al. (1988)
    - Minimum entrainment rate:
        - $\mu\_min = 0.2/D$
        - D, diameter for the largest convective plume
- Stochastic determination of the Tokioka Limit
    - determined in *random*
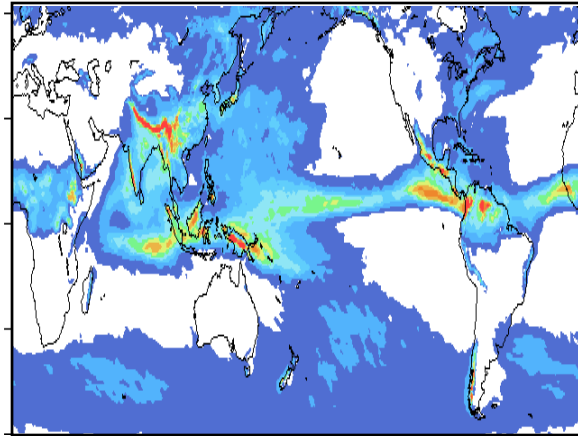- Selective suppression of RAS convection scheme

Mostly highly-entraining Shallow plumes

Occasional deep plumes

Probability (y-axis)

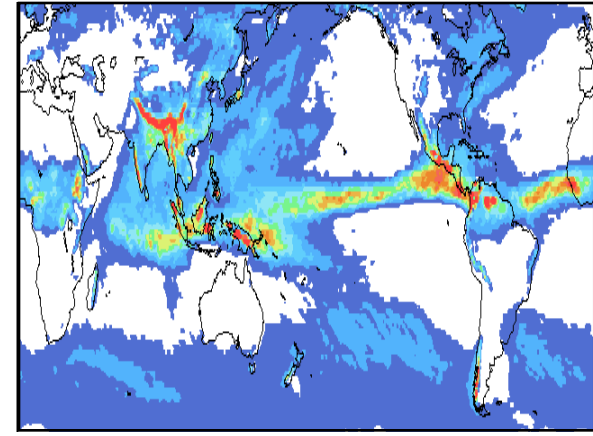**Minimum Cumulus entrainment** (x-axis)

y=x^-1/2

Seasonal-mean Precipitation (JJA 2005-06)

GPCP

CTRL (50 km)

New Tokioka (50 km)

CTRL (25 km)

New Tokioka (25 km)

mm/d

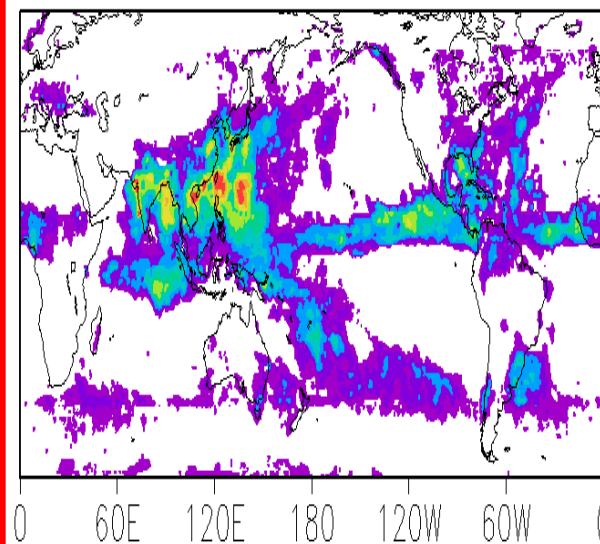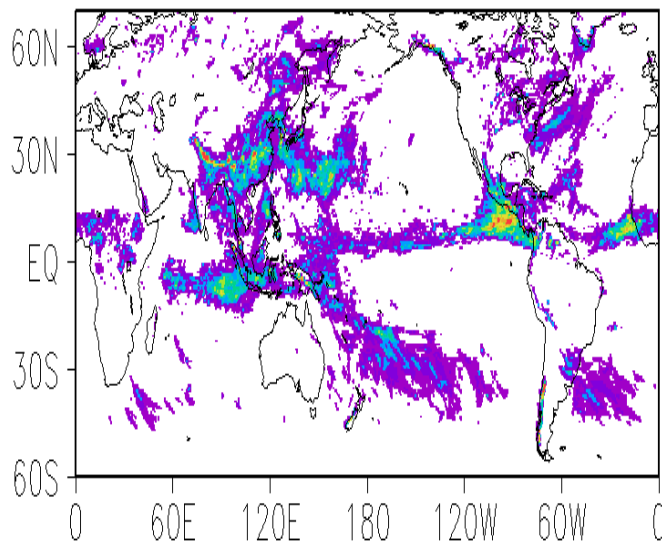2 4 6 8 10 12 14 16 18 20
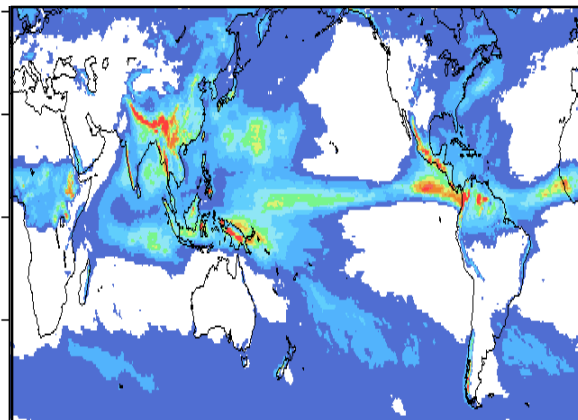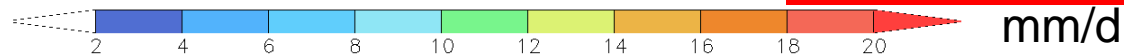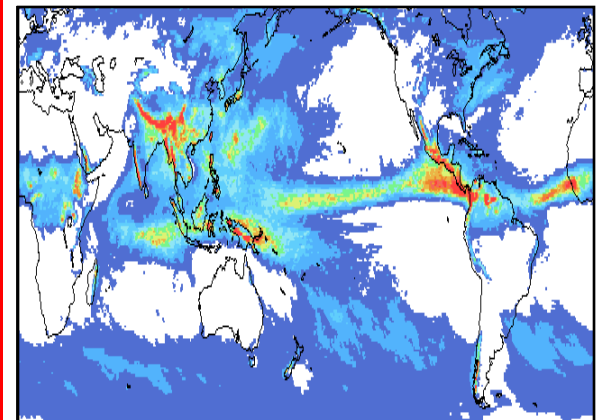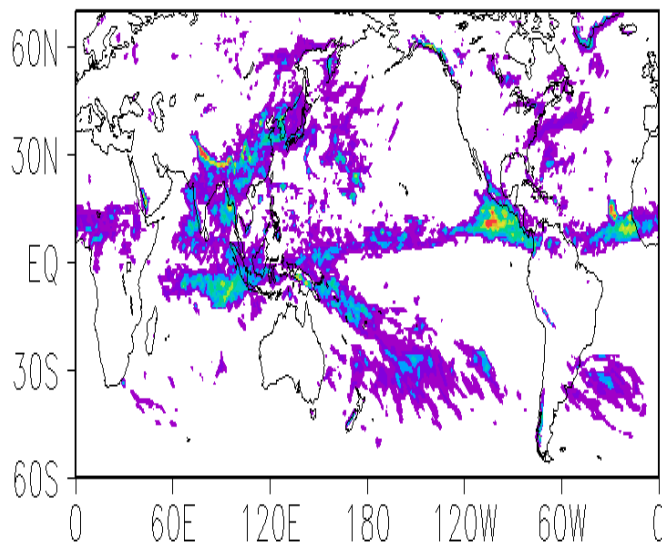
CTRL (50 km)
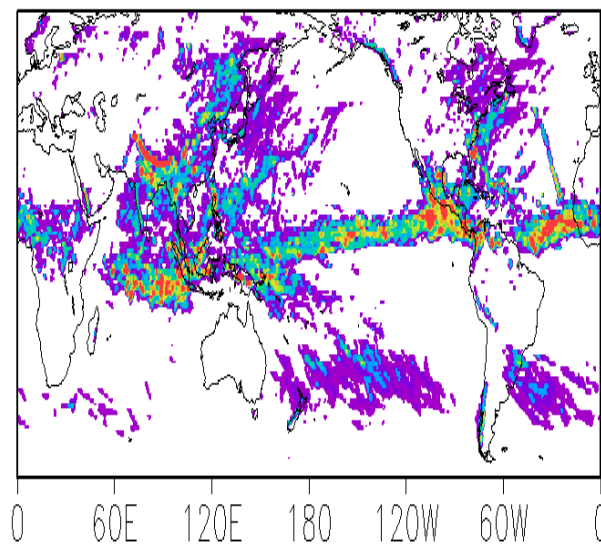
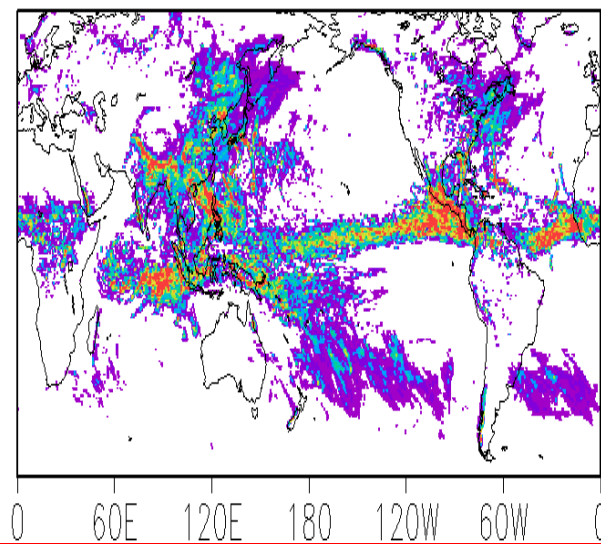**New Tokioka (50 km)**

GPCP

CTRL (25 km)

New Tokioka (25 km)

Variance of Daily Precipitation (JJAS)

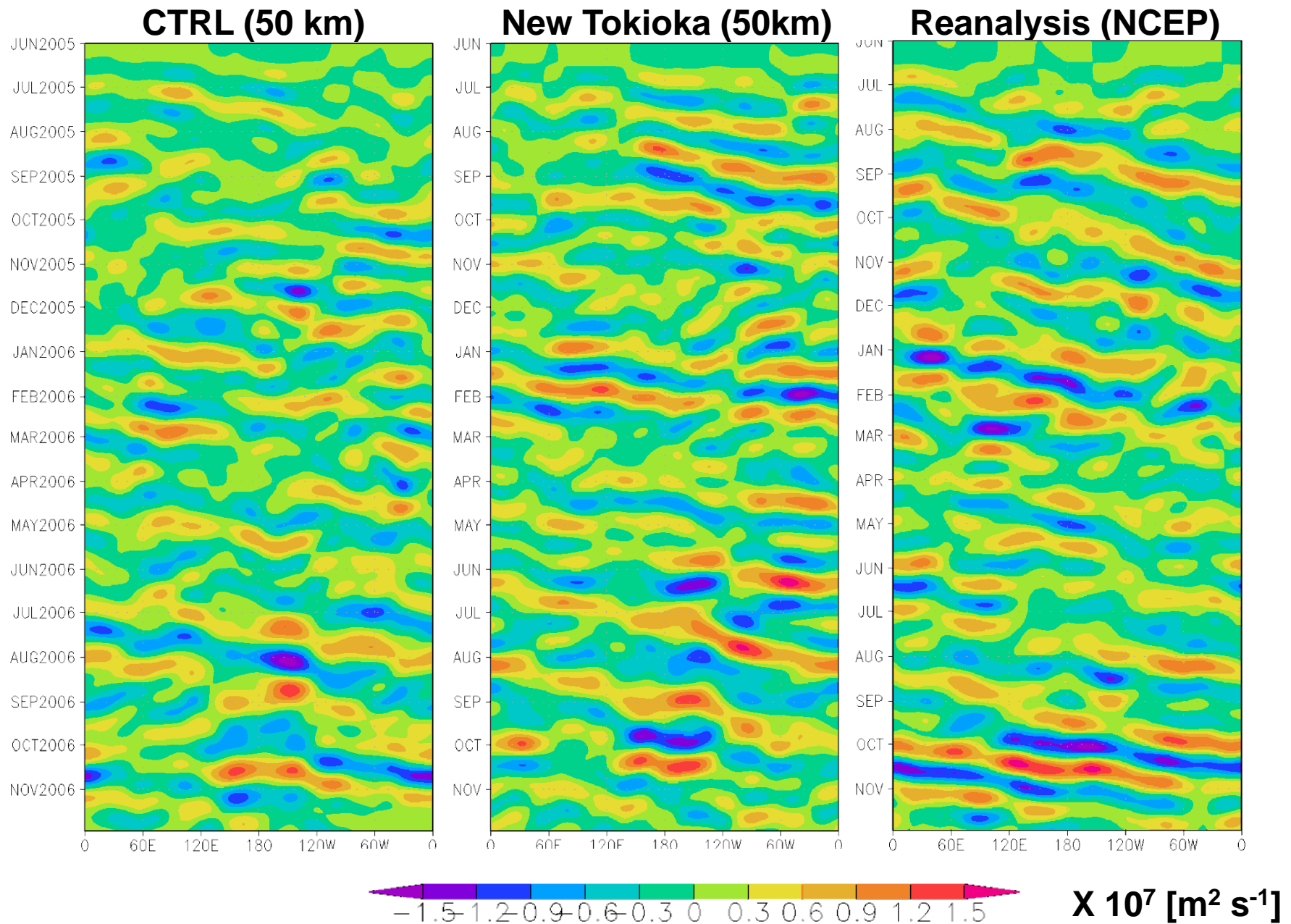# Hovmuller Precipitation (10S-10N avg)

CTRL (50 km) **New Tokioka (50km)** **OBS (GPCP)**

[mm/d]
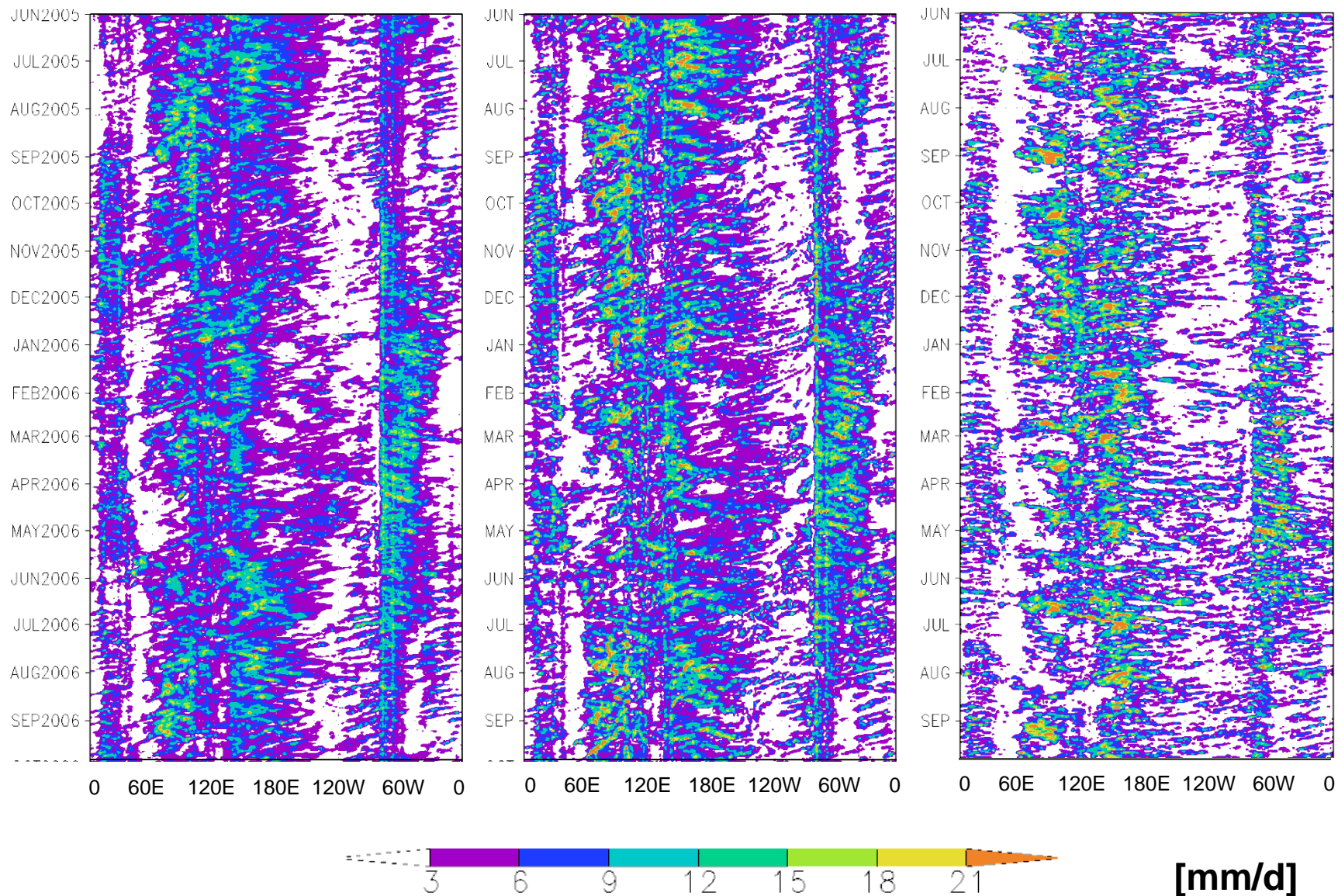
200-mb Velocity Potential (10S-10N avg, 20-70d filtered)
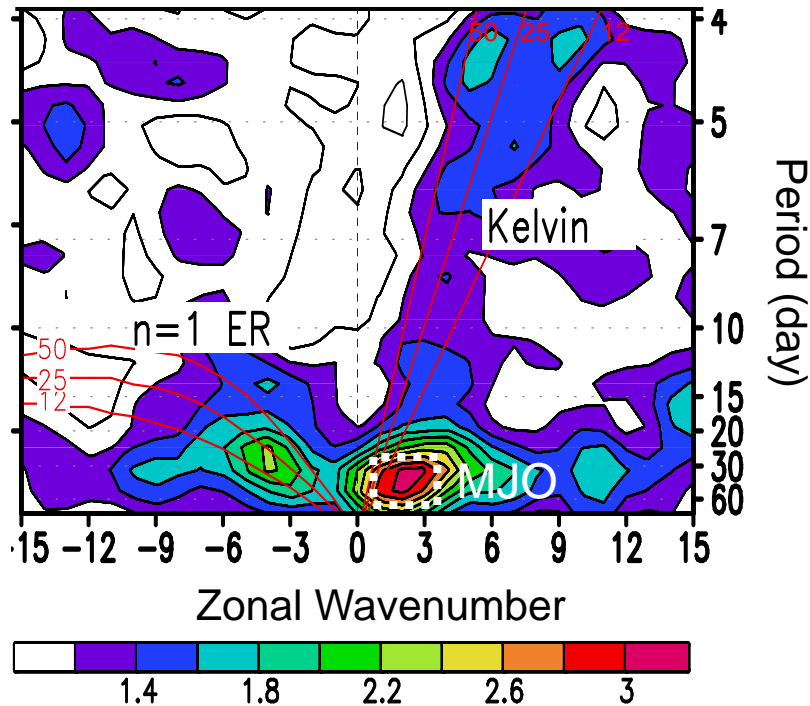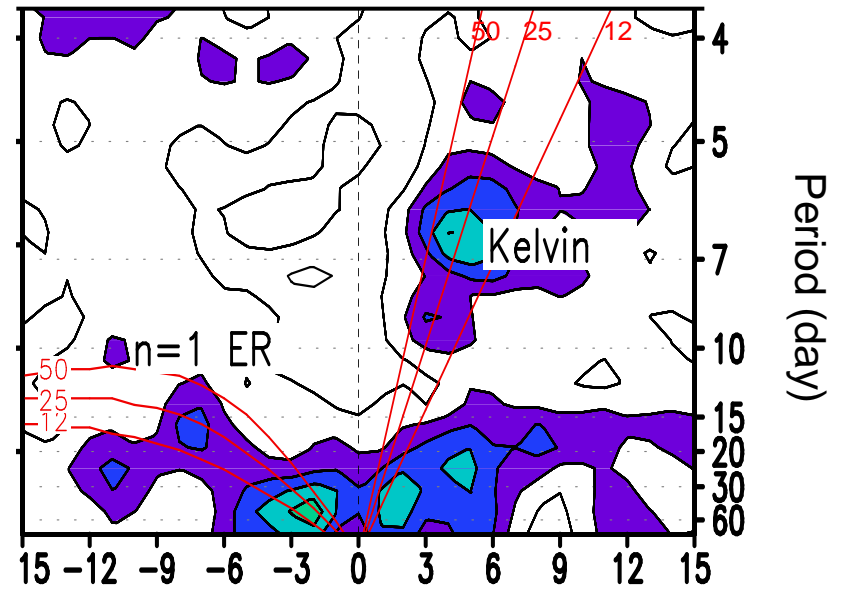
CTRL (50 km)   **New Tokioka (50km)**   **Reanalysis (NCEP)**

X 10⁷ [m² s⁻¹]

Tropical Waves and MJO

Observed (GPCP 1DD)

CTRL (50 km)

New Tokioka (50 km)

Kelvin

n=1 ER

MJO

Zonal Wavenumber

Period (day)
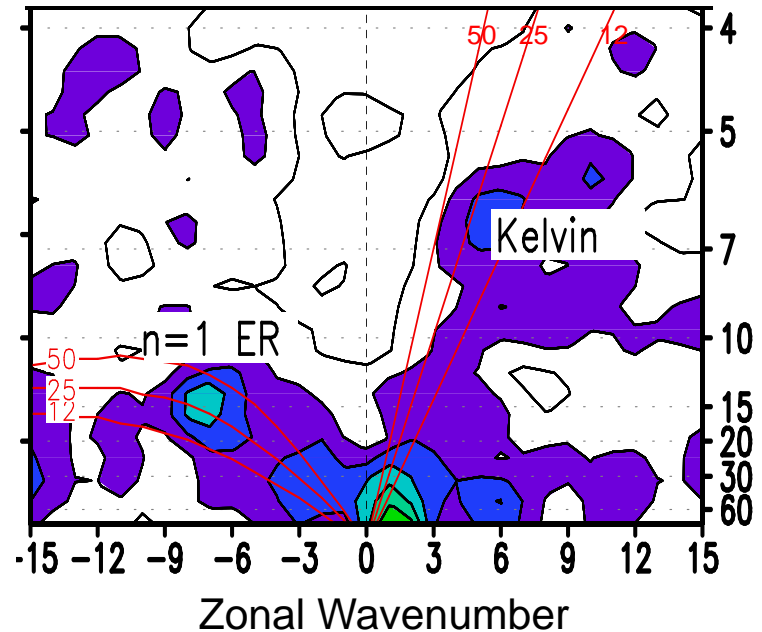
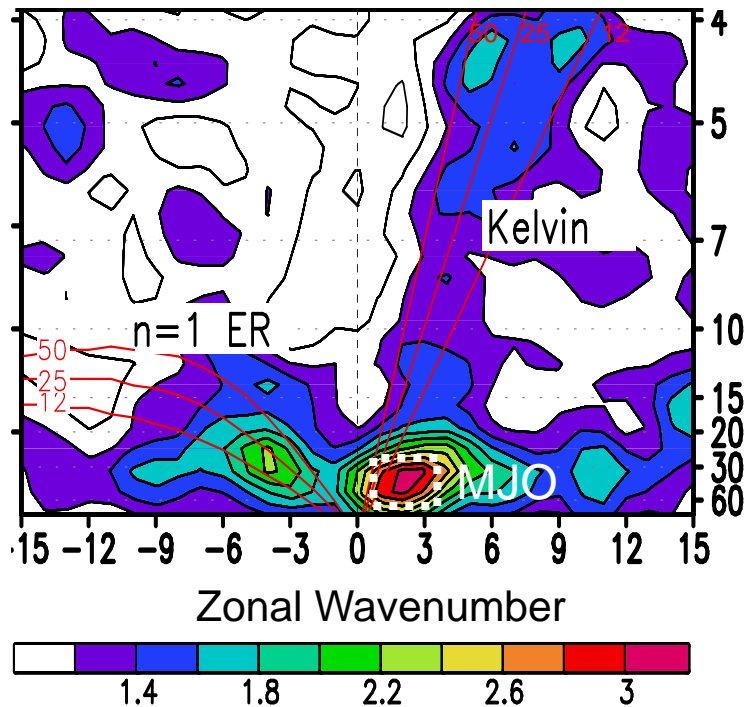Power Spectrum of Precipitation
Tropical Belts (10S-10N)

Symmetric Component

Tropical Waves and MJO

Observed (GPCP 1DD)

CTRL (25 km)
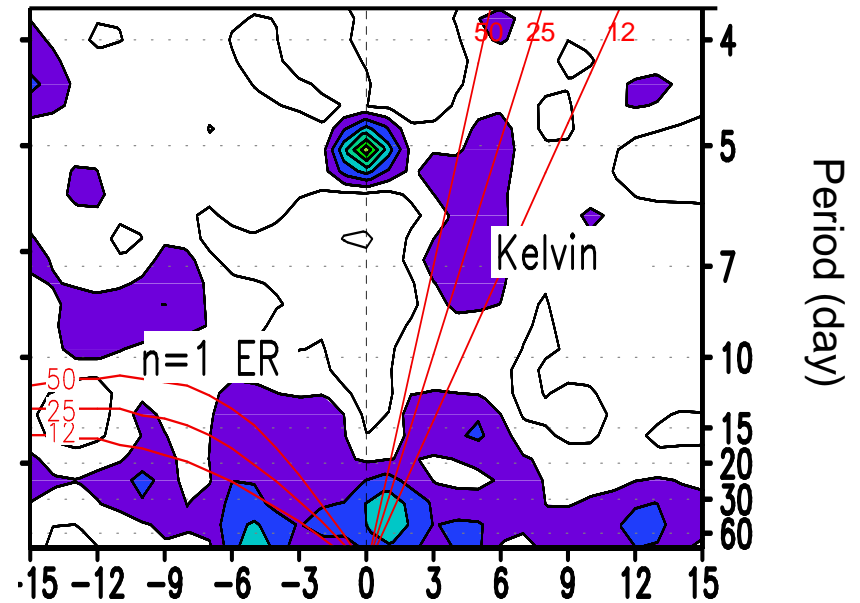
New Tokioka (25 km)

Kelvin

n=1 ER

MJO

Period (day)

Zonal Wavenumber

1.4   1.8   2.2   2.6   3
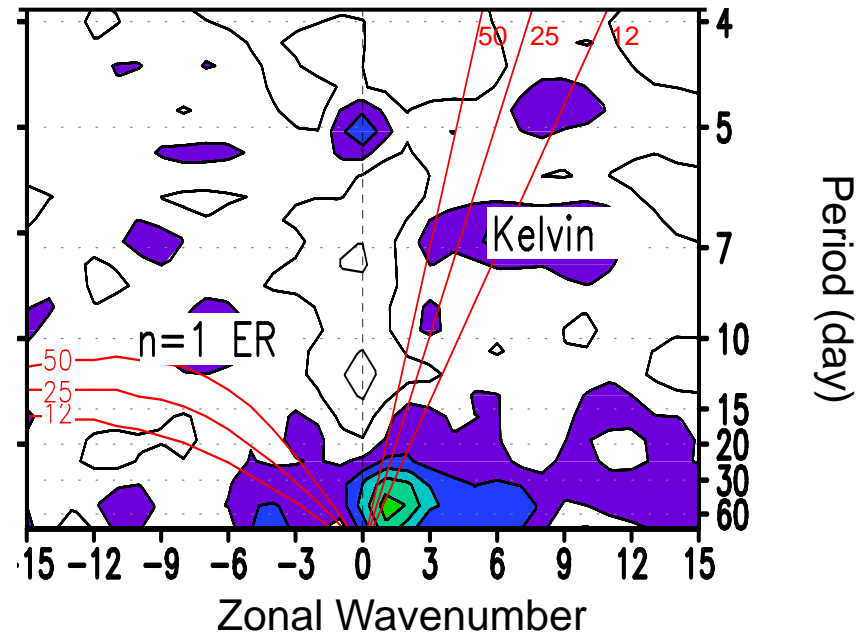
Power Spectrum of Precipitation
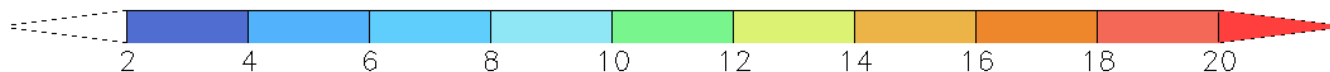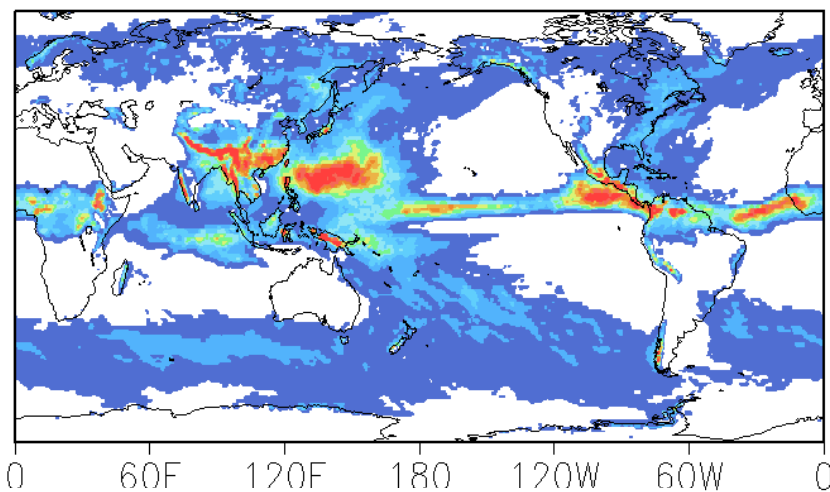Tropical Belts (10S-10N)

Symmetric Component

Comparison between *Fixed* and *Stochastic* Tokioka Modification

(Compared in the 50-km simulations)

Seasonal-mean Precipitation (JJAS, 1999)
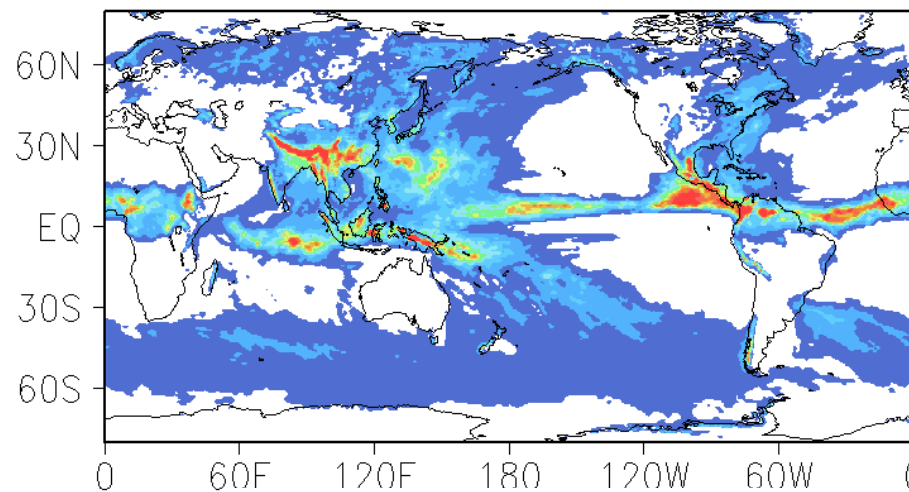
Precipitation Variance
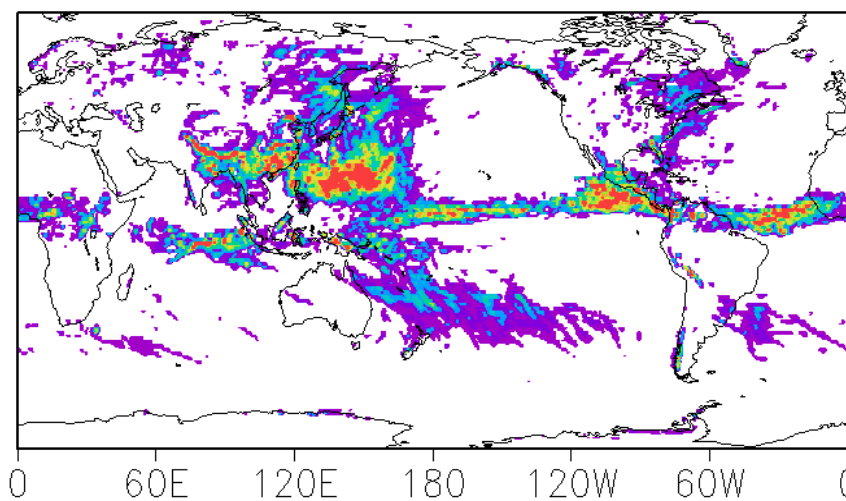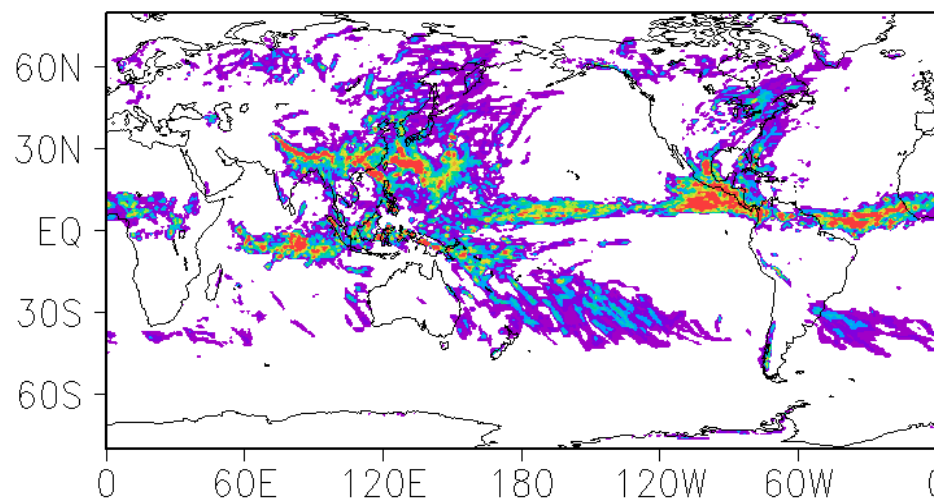
Hovmuller Precipitation (10S-10N avg)

Stochastic | *Fixed* | *GPCP (obs)*
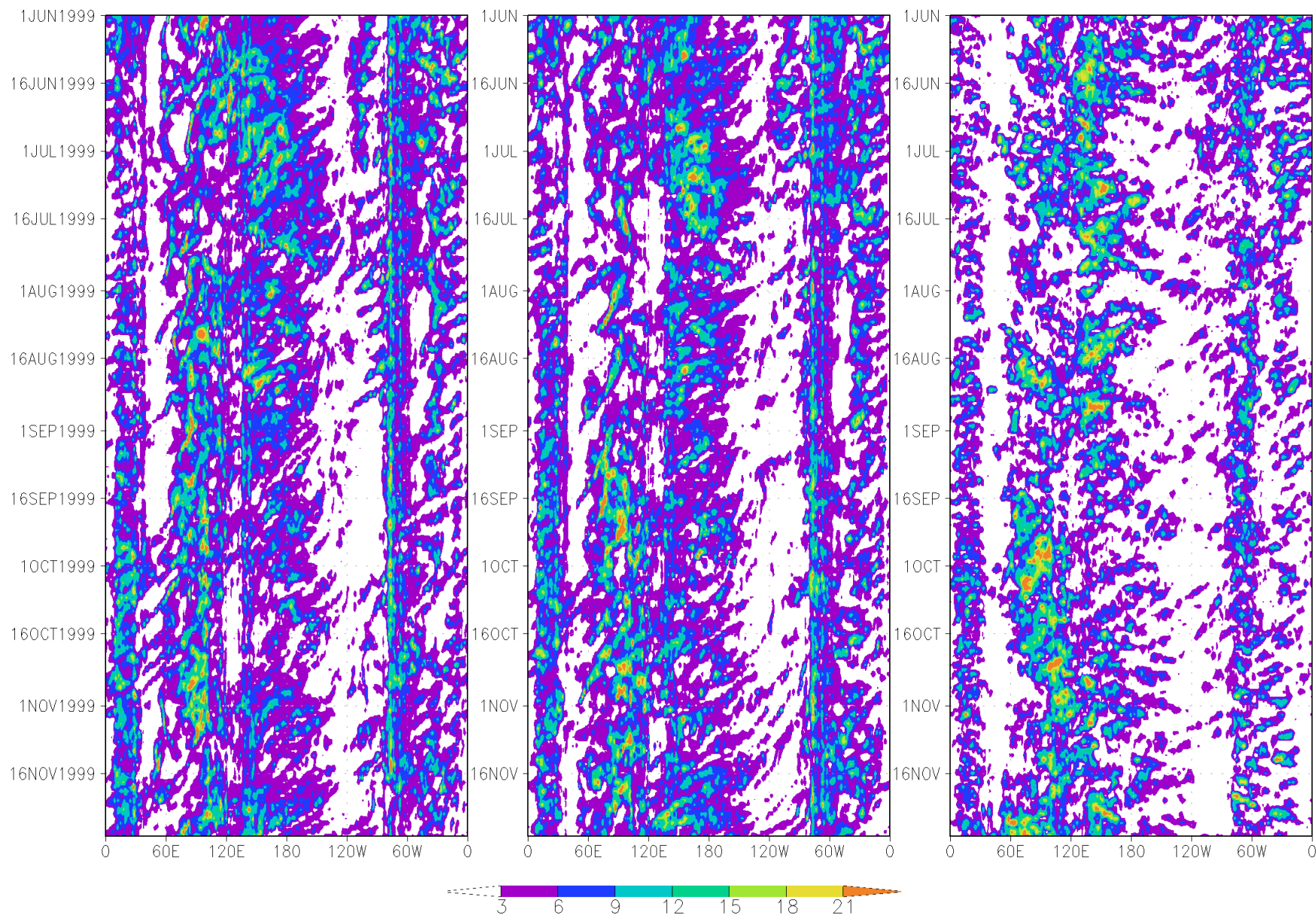
Tropical Storm Simulations

- Control vs Modified RAS (New Tokioka)
- 50-km and 25-km resolution runs
- AMIP-style with the weekly OISST
- Period: 15 May 2005 – 1 Dec 2006
- 2 Hurricane Seasons of 2005 and 2006

Contrasting Two Seasons in 2005 and 2006

2005

2006

27 Tropical Storms

10 Tropical Storms

Image source: http://www.wunderground.com
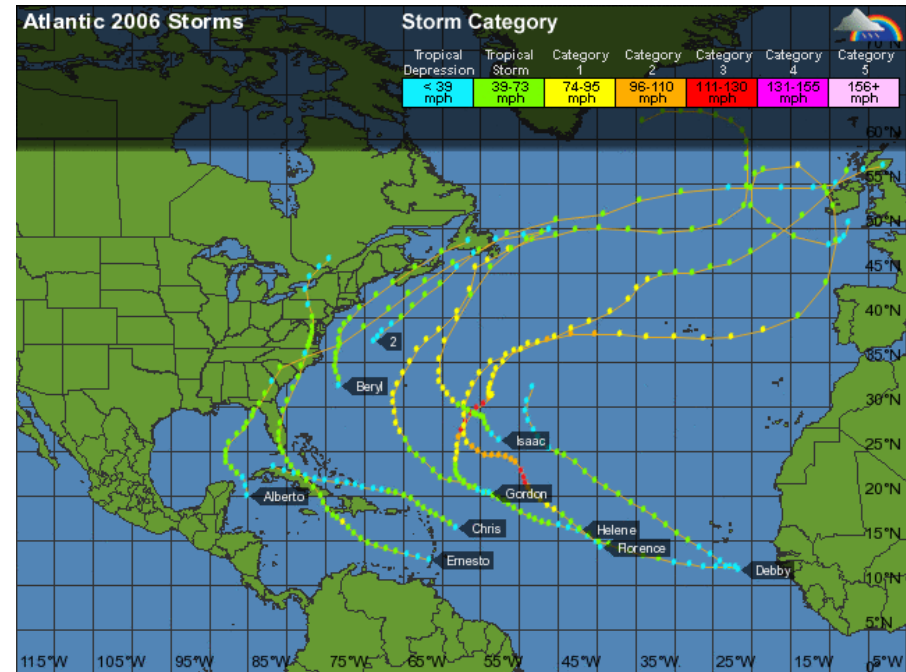
Tropical Storms Tracking

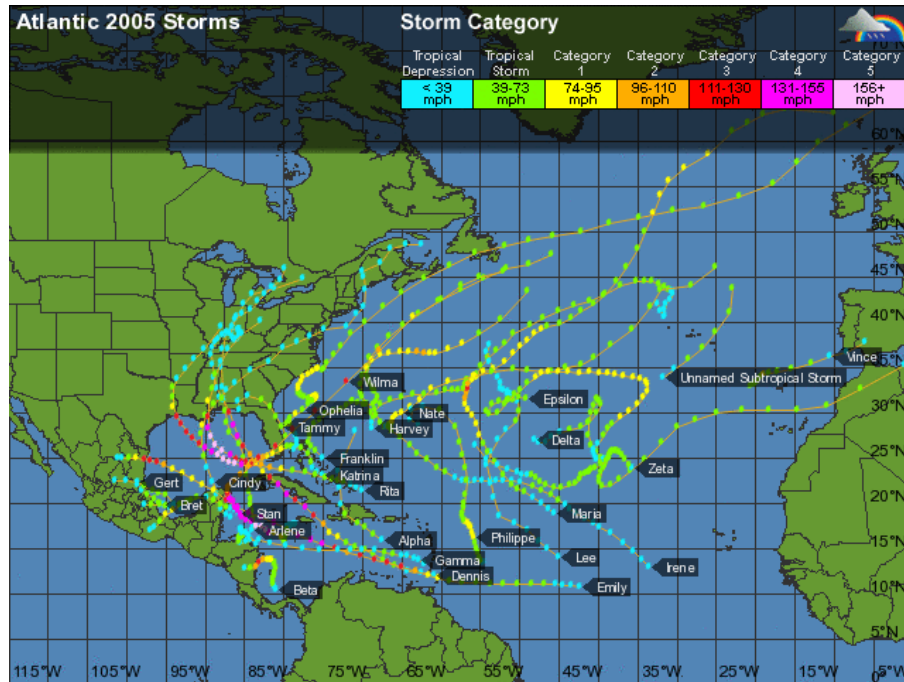- Tracking tools based on the method of Camargo and Zebiak (2002); basin-dependent thresholds of vorticity@850, 10-m wind, and vertically integrated temperature anomaly

- NCEP/CPC tracking version (Lindsey Long/Jae Schemm)

- Applied to 3 hourly, native grid outputs

Strongest Hurricane in the "New Tokioka" 25-km Run
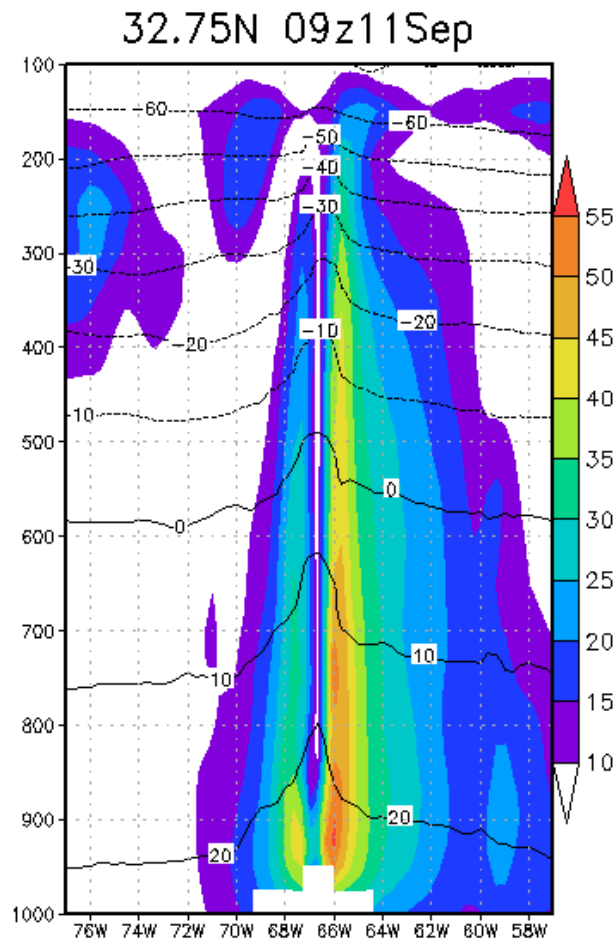
Zonal
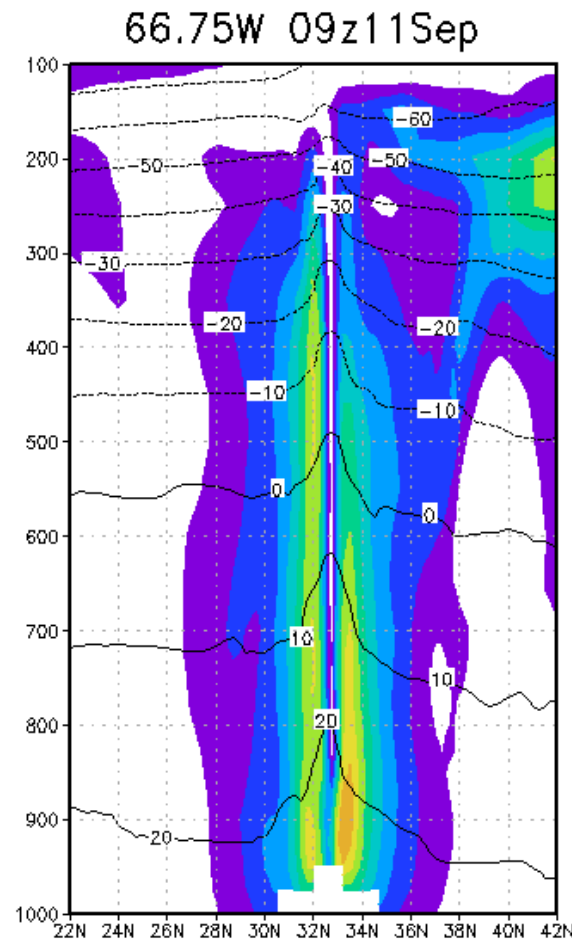
Meridional

Wind up to 60 m/s
Wind max at less Than 900hP
Exceptionally well-defined warm core
Very realistic scale

Min Pressure~960 hPa

Tropical Storm Simulations (50-km resolution)
Contrasting Two Seasons in 2005 and 2006
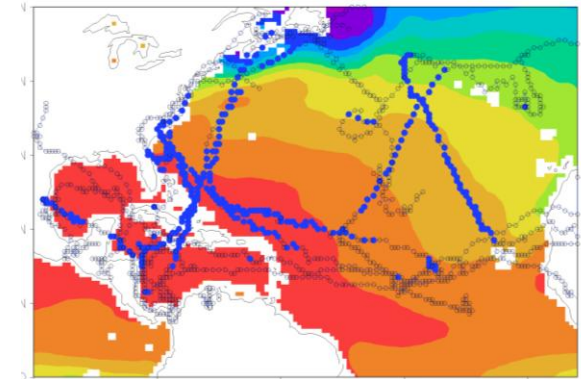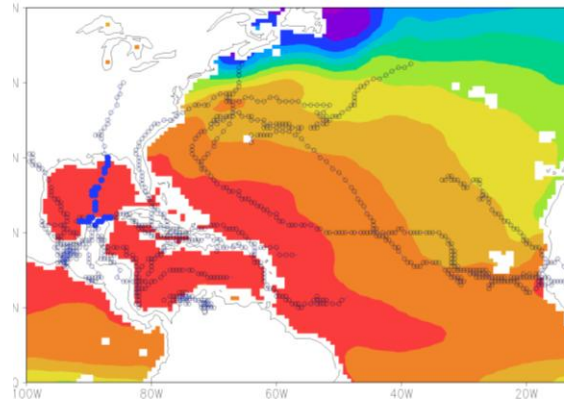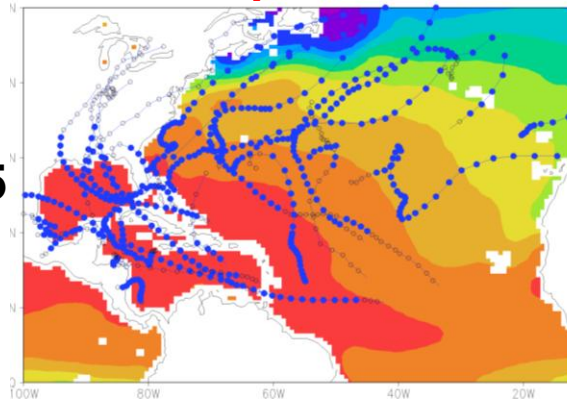

Obs (Best Track)   **Control**   **Modified**

27 Tropical Storms   16 TSs
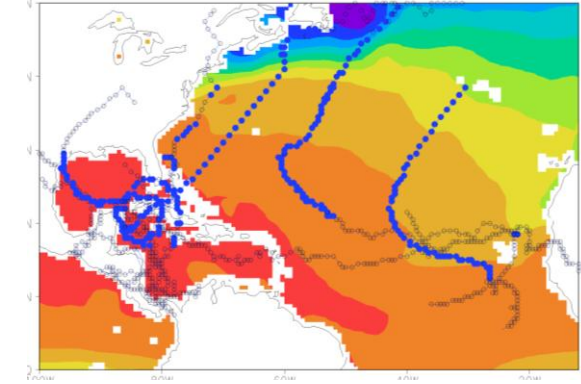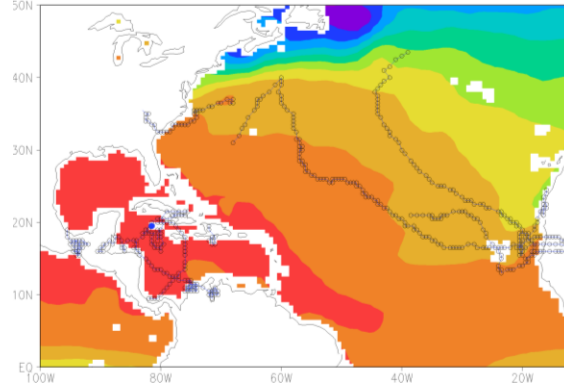
2005

10 Tropical Storms   7 TSs
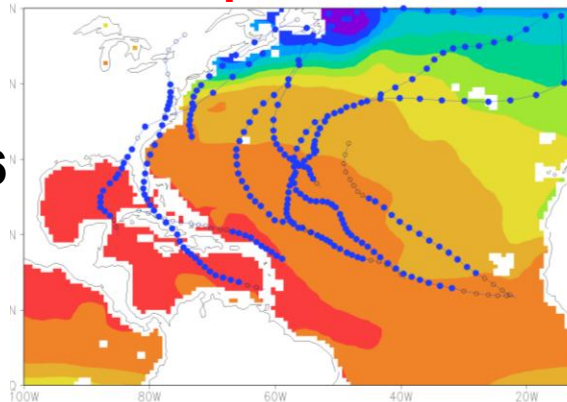
2006

SST (K)

● **Location defined as a tropical storm (max 10-m wind > 34 knots)**

Multi-Year Ensemble Simulations for Tropical Storm

- Modified RAS (New Tokioka)
- ½-deg runs with different SST
    1997, 1998, 1999
    2004, 2005,2006,2007
- 5 member ensembles for each year
- Initialized at 15 May
- Integration for 15 May to 1 December

Tropical Storm Tracks

Observations (Best Track,1997-2007)   GEOS-5 (7 years,ens1)
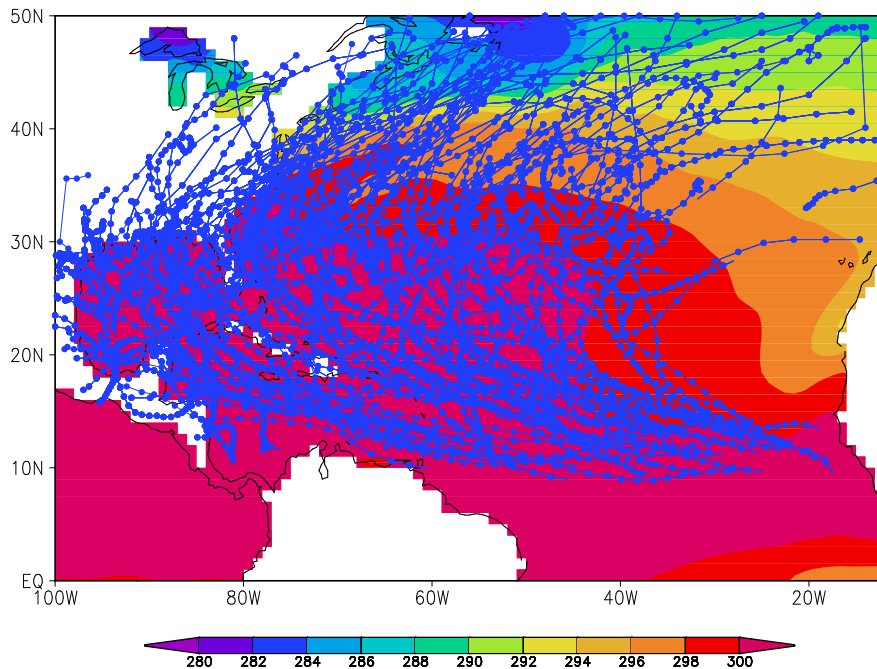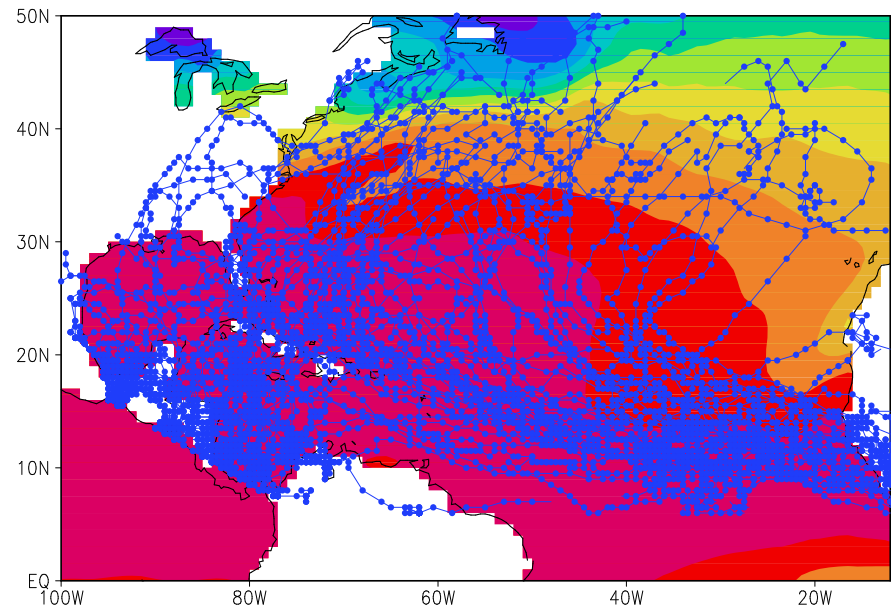
Shaded: SST (1997-2007)

Tropical Storm Maximum Intensity
(1997-2007)

Model winds @ 850 hPa, instantanous

Tropical Storm Origins
(August-October)

Observations (Best Track, 1998-2005)   **GEOS-5 (50 km,7 years x 5 ensembles)**
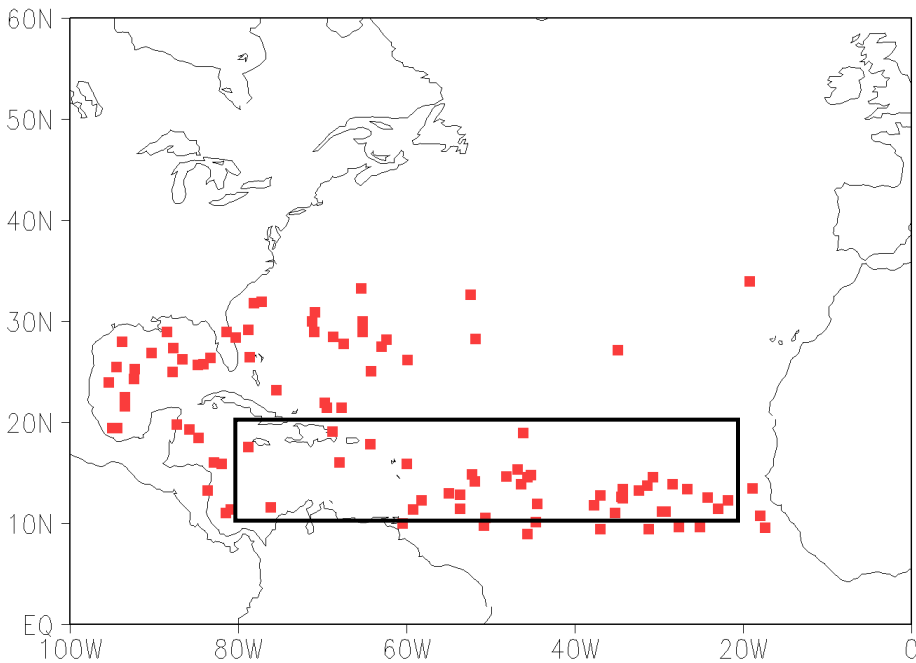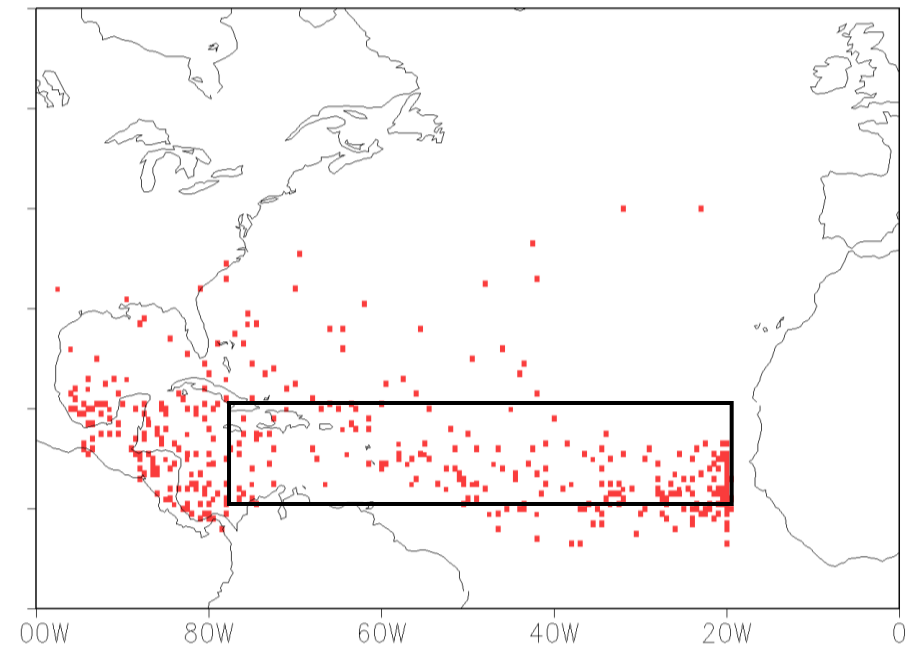
Box: Main Development Region (MDR)

Annual Cycle of Tropical Storm Origins (GEOS-5)

Number of Tropical Storms in Atlantic
(16 may to 30 November)

Summary

- At resolutions of 25-50 km, the convective parameterization is still required. It plays a dominant role in dictating mean climate and the temporal variability.

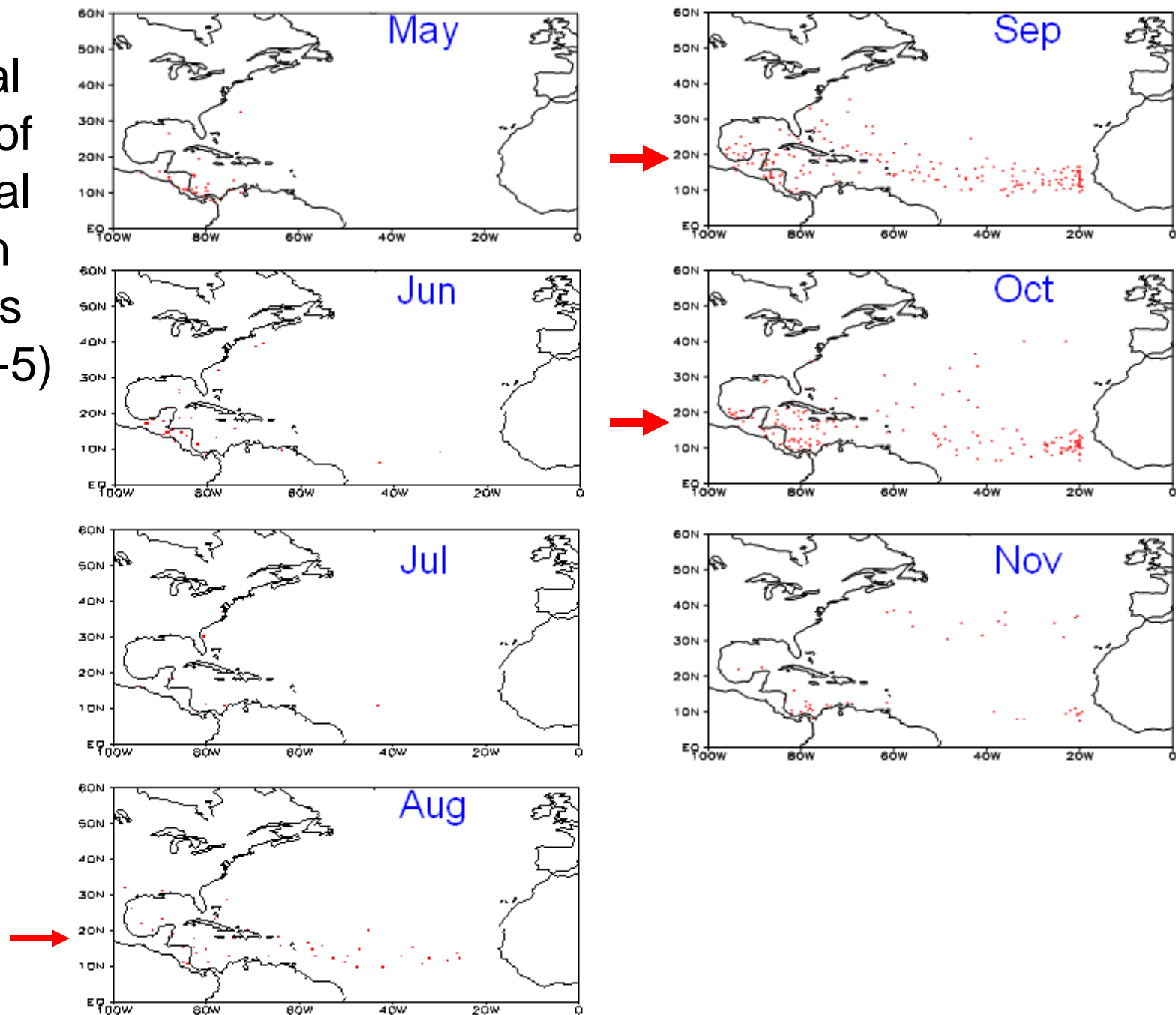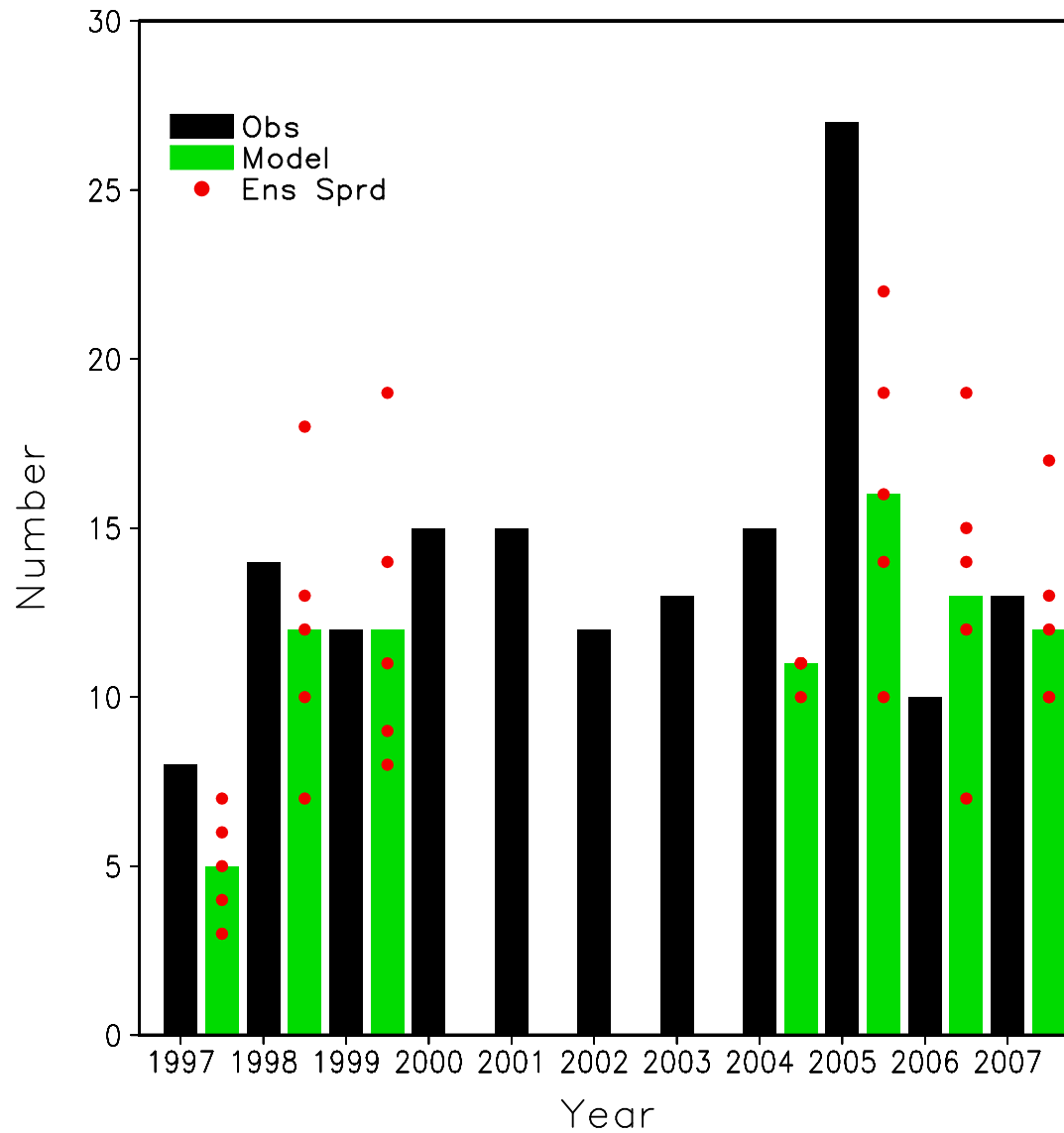- There should be many potentials to improve the parameterization in high-resolution climate modeling: Stochastic treatment for cumulus entrainment process is one example (e.g., MJO and tropical storms).

- The GCM produces reasonable structure of the tropical storm and its space-time variability over the Atlantic Ocean.

- More diagnostics are underway to explore the relationship of the tropical storm with SST, MJO, and African Easterly Jets/Waves.

Thank you very much!

Spare plots

Threshold values obtained from GEOS-5 simulation

Atlantic Ocean

	MERRA	GEOS-5 (Stochioka)
period	1998-2005	7 yrs (1997,98,99, 04,05,06,07)*5 members
resolution	1 degree	½ degree
ξ_{thresh} (s-1)	3.2728538E-05	3.0312378E-05
υ_{thresh} (m/s)	3.352803	2.529708
T_{thresh} (K)	0.2392231	0.2119271